TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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WIND-TUNNEL TESTS OF THREE LATERAL-CONTROL DEVICES IN COMBINATION WITH A FULL-SPAN SLOTTED FLAP ON AN N.A.C.A. 23012 AIRFOIL

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SUMMARY

A large-chord N.A.C.A. 23012 airfoil was tested in the closed-throat 7- by 10-foot wind tunnel. The airfoil extended completely across the test section, and two-dimensional flow was approximated. The model was fitted with a full-span slotted flap having a chord 25.66 percent of the airfoil chord. The ailerons investigated extended over the entire span and each had a chord 10 percent of the airfoil chord. The types of ailerons tested were: retractable ailerons, slot-lip ailerons using the lip of the slot for ailerons, and plain ailerons on the trailing edge of the slotted flap.

The data are presented in the form of curves of section lift, drag, and pitching-moment coefficients for the airfoil with flap deflected but with ailerons neutral, and of rolling-moment, yawing-moment, and hinge-moment coefficients calculated for a rectangular wing of aspect ratio 6 with a semispan aileron and a full-span flap.

For the ailerons investigated the data indicate that, from considerations of rolling and yawing moments produced and of stick forces desired, the retractable aileron is the most satisfactory means of lateral control for use with a full-span slotted flap.

INTRODUCTION

Many types of trailing-edge flap have been developed for producing high lift coefficients. These flaps usually extend over only the inboard section of the wing because the outer portion is required for lateral-control devices.

With such an arrangement, the average lift for the entire wing is less and the drag is more for a given lift than it would be if the flap extended over the entire span. The increase in the lift-drag ratio obtained with full-span flaps over that with partial-span flaps is especially important for the condition of take-off with flaps deflected.

The purpose of the present investigation was to determine the effectiveness of various lateral-control devices when used with a full-span flap. An arrangement of the full-span slotted flap reported in references 1 and 2 was used because that flap appears to be one of the most promising high-lift devices developed up to the present time.

Three types of aileron were investigated:

1. Slot-lip (references 3 and 4).- The lip of the flap slot was hinged to move up so as to change the slot shape and also to act as a "spoiler" on the upper surface of the airfoil.

2. Plain.- The trailing edge of the slotted flap was hinged to move as a plain aileron.

3. Retractable (reference 5).- A curved plate was installed that moved out of the upper surface of the airfoil ahead of the flap to act as a "spoiler."

APPARATUS AND TESTS

Model

The airfoil was built to the N.A.C.A. 23012 profile with a mahogany nosepiece, a pine flap and slot form, and the intermediate section of ribs was covered with tempered waterproofed wallboard. The model has a 3-foot chord and a 7-foot span. The chord of the flap, which extended along the entire length of the span, was 0.2566c. The airfoil profile, the slot and the flap dimensions, and the locations of the flap when deflected are given in figure 1(a) and in table I. Figures 1(b) to 1(d) show the arrangements of the ailerons with their locations and dimensions.

General Test Conditions

The model completely spanned the closed test section of the wind tunnel so that two-dimensional flow was practically attained. The two-dimensional-flow installation in the 7- by 10-foot closed-throat wind tunnel is described in reference 1. The aileron hinge moments were measured with a torque-rod balance.

A dynamic pressure of 16.37 pounds per square foot was maintained for all tests. This dynamic pressure corresponds to an air speed of about 80 miles per hour and to an average test Reynolds Number of 2,190,000.

Measurements of lift, drag, and pitching moment were made for each aileron setting through a complete range of angles of attack up to the stall, with flap deflections (δ_f) of 0°, 10°, 20°, 30°, 40°, and 50°. The aileron settings (δ_a) were (minus, up; plus, down):

For the slot-lip aileron, 0°, -5°, -10°, -20°, -30°, -45°, and -60°.

For the plain aileron, -40°, -30°, -20°, -10°, 0°, 10°, 20°, 30°, 40°, 50°, and 60°.

For the retractable aileron, 0, up 0.0333c, 0.0667c, and 0.10c.

Because of possible structural advantages, narrow-chord retractable ailerons were tested with deflections greater than the aileron chords so that a gap was left between the upper surface of the airfoil and the bottom of the aileron. One aileron with a chord 0.0667c was tested up 0.10c, and one aileron with a chord 0.0333c was tested up 0.0518c and 0.0686c. The chords of the retractable ailerons were measured along their suspended arc.

RESULTS

Airfoil Section Coefficients

The airfoil section coefficients are given in standard nondimensional coefficient form as follows:

c_l, section lift coefficient, l/qc.

c_{d_o}, section profile-drag coefficient, d/qc.

$c_{m_{(a.c.)_o}}$, section pitching-moment coefficient about aerodynamic center of airfoil with flap and aileron neutral, m/qc^2.

where l is section lift.

d, section profile drag.

m, section pitching moment.

q, dynamic pressure, $\frac{1}{2} \rho V^2$.

c, airfoil chord including flap.

α_o, section angle of attack.

Aileron Coefficients

C_{h_a}, aileron hinge-moment coefficient, $h_a/(q\ c_a\ S_a)$.

where h_a is aileron hinge moment about the aileron hinge.

c_a, aileron chord.

S_a, aileron area.

C_l', rolling-moment coefficient.

C_n', yawing-moment coefficient.

Rolling-moment and yawing-moment coefficients for a rectangular wing of aspect ratio 6 with one semispan aileron were computed from the two-dimensional-flow tests by the following method:

$$C_l' = \left[-0.0071/(dc_l/d\alpha)\right] \Delta c_{l_1}.$$

$$C_n' = C_{n_i}' + C_{n_o}'$$

where $C_{n_i}' = -0.180\ C_l'\ c_{l_2}$, and $C_{n_o}' = 0.125\ \Delta\ c_{d_o}$.

$dc_l/d\alpha$ is the average of the slopes of the lift curves (Δc_l per degree) for the airfoil with aileron neutral and for the aileron deflected.

Δc_{l_1}, the increment in the section lift coefficient produced by the deflected aileron at any given value of angle of attack α.

$C_{n_i}{}'$, the induced yawing-moment coefficient produced by the increment of section lift (Δc_{l_1}).

c_{l_2}, the average c_l of the airfoil when the aileron is deflected on one side.

$C_{n_o}{}'$, the yawing-moment coefficient due to the increment of profile drag (Δc_{d_0}) produced by the deflected aileron.

(The constants -0.0071 and -0.180 are taken from figure 13(a) of reference 6. These constants include the effects of aspect ratio and lift distribution produced by the deflection of the aileron on one side. The constant 0.125 assumes that the profile drag produced by the aileron is concentrated at the center of the aileron span.)

Accuracy of Results

Experimental errors in the results presented in this report are believed to be within the following limits:

c_l - - - - - - - - - - - - - ±0.02 (near maximum lift)

c_{d_0} - - - - - - - - - - - - - ±0.0003 (minimum drag with $\delta_f = 0^\circ$)

$C_l{}'$ - - - - - - - - - - - - - ±0.005

$C_n{}'$ - - - - - - - - - - - - - ±0.002

C_{h_a} - - - - - - - - - - - - - ±0.005

α - - - - - - - - - - - - - ±0.5°

δ_f - - - - - - - - - - - - - 0° to -1.0°

Flap position - - - - $\pm 0.002c$

δ_a - - - - - - - - - - - $\pm 0.3^\circ$

Aileron position - - - $\pm 0.0003c$

No tests were made to determine the effect of flap and aileron fittings on the results. The lift and the drag have been corrected for tunnel-wall effects, as explained in reference 1. The effects of the fittings and the tunnel corrections probably would not appreciably change the rolling or the yawing moments given in this report.

The given limits of accuracy do not include any uncertainties in the assumptions used for computing C_l' and C_n'. The same relations, however, were used in this report for all coefficients.

DISCUSSION

Characteristics of Airfoil with Slotted Flap

The section characteristics of the airfoil with aileron neutral and the slotted flap deflected are given as curves of c_l, c_{d_o}, and $c_{m_{(a.c.)_o}}$ plotted against the section angle of attack α_o in figure 2. These data are given to show the general characteristics of the slotted flap. As previously mentioned, the data were not corrected for the effects of the aileron and the flap fittings.

Aileron Characteristics

The rolling-moment, the yawing-moment, and the hinge-moment coefficients computed as previously described are given in the form of curves of the coefficients plotted against aileron deflection. The coefficients are all given for a rectangular wing of aspect ratio 6 with the full-span flap and for a single aileron extending over the entire semispan. The data are given in this form so that all ailerons will be on a convenient basis for comparison.

An indication of aileron performance may be obtained from the wind-tunnel data by consideration of the following factors:

1. The value of C_l' should increase with lift coefficient, i.e., it should increase with angle of attack and with flap deflection so that the airplane will have about the same response for a given control movement regardless of flying attitude.

2. The value of C_l' should increase with aileron deflection, and $dC_l'/d\delta_a$ should be large for small aileron deflections.

3. Lag in rolling motion with control movement should be small, probably less than 1/10 second (reference 7).

4. The values of C_n' should be small in any case and preferably favorable (positive when C_l' is positive).

5. The hinge moments of one aileron should be small or of such a nature that they can be counterbalanced against those of the other aileron through a differential linkage.

6. The control force required to deflect the ailerons should be small and should increase uniformly with aileron deflection unless a servocontrol mechanism, such as hydraulic operation of the ailerons, is used.

<u>Slot-lip aileron</u>.- The rolling-moment coefficients for the slot-lip aileron are unsatisfactory for the condition from $\delta_f = 0°$ to $\delta_f = 20°$ with aileron angles less than $10°$ because about $10°$ movement of the ailerons from neutral is required before any appreciable amount of rolling moment is obtained (fig. 3). The lag in rolling motion with control movement is probably less than 1/10 second. (See references 3 and 4.)

The yawing-moment coefficients are generally adverse (negative) for small aileron deflections and favorable (positive) for large aileron deflections. These moments generally become algebraically less as the flap angle is increased (fig. 3).

The hinge moments required to hold the aileron neutral are large and increase with flap deflections (fig. 4). As the aileron is moved up, the moments change sign and force must be applied to move the aileron higher. The slopes of the curves of C_{h_a} against δ_a are irregular and, for small flap deflections, they change sign. The

fact that the hinge moments are irregular, combined with the condition that only one aileron is moved, necessitates a complicated control linkage if satisfactory stick forces are to be obtained unless a servocontrol mechanism is used.

Plain aileron.- The rolling-moment coefficients for the plain aileron on the flap decrease with increased flap deflection. A value of C_l' of 0.04 (indicated as a minimum satisfactory value in reference 6) or larger may be obtained provided that the flap deflection does not exceed 40° and that both ailerons are deflected (fig. 5).

The values of the yawing-moment coefficient (fig. 5) would generally be adverse and large, especially with large flap deflections.

The hinge moments are comparatively small for small flap deflections but they become large with increasing flap deflections (fig. 6). The curves of C_{h_a} against δ_a are fairly regular and, as one aileron is moved down, the other can be made to move up and the moments will balance when $\delta_a = 0^\circ$. Because the hinge moments increase with flap deflection, any appreciable amount of differential would cause overbalance with flaps deflected.

Retractable aileron.- The rolling-moment coefficients for the retractable aileron are satisfactory for flap angles of 40° or less (fig. 7). For the flap angle of 50°, the rolling moments are less than those for the 30° flap angle. The yawing moments are favorable for 0° angle of attack, becoming less as the angle of attack is increased, and at 12° they are adverse except for the condition of $\delta_f = 0^\circ$, $\delta_a = -0.10c$. The hinge moments were not measured because this type of aileron has no aerodynamic hinge moment when the hinge is located at the center of the aileron radius. It appears that a satisfactory "feel" for the control could be obtained by placing the hinge axis slightly below the center of the aileron radius.

Figures 8 and 9 show the effects of using narrow-chord retractable ailerons and deflecting them through a range greater than the aileron chord, leaving a gap between the wing and the lower edge of the aileron. In practically all cases the rolling-moment and yawing-moment coefficients were reduced but the percentage reduction was less than the reduction in aileron chord. When the gap between the aileron and the wing was too great, a sharp

break occurred in the lift and drag. This break would show as a sharp discontinuity in the curves of rolling-moment and yawing-moment coefficients if plotted against angle of attack. The break occurred only with the flap deflected and with the 0.0333c aileron deflected 0.0686c. The maximum angle of attack at which the break occurred was 3° with the flap deflected 20°.

The lag in rolling motion with control movement would probably be less than 1/10 second for a retractable aileron as far back on the wing as those tested. (See reference 3.)

CONCLUDING REMARKS

When all factors are considered with regard to the rolling and the yawing moments produced and of the stick forces desired, the retractable aileron is the only one of the three ailerons tested that would be satisfactory when used in combination with the full-span slotted flap. The retractable aileron may be deflected through a somewhat greater range than its chord with an increase in rolling and yawing moment.

The plain ailerons on the slotted flap were unsatisfactory because of the small rolling moments and large adverse yawing moments produced with large flap deflections. The slot-lip aileron as tested would be unsatisfactory for lateral control because of the ineffectiveness of the ailerons for deflections less than 10° with small flap deflections. The characteristics of the hinge moments of the plain and the slot-lip ailerons are such that they are likely to cause difficulties in obtaining satisfactory stick forces.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., July 14, 1938.

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TABLE I

Ordinates for Airfoil and Slot Shapes

(Stations and ordinates in percent of airfoil chord)

N.A.C.A. 23012 Airfoil		
Station	Upper surface	Lower surface
0	-	0
1.25	2.67	-1.23
2.50	3.61	-1.71
5	4.91	-2.26
7.5	5.80	-2.61
10	6.43	-2.92
15	7.19	-3.50
20	7.50	-3.97
25	7.60	-4.28
30	7.55	-4.46
40	7.14	-4.48
50	6.41	-4.17
60	5.47	-3.67
70	4.36	-3.00
80	3.08	-2.16
90	1.68	-1.23
95	.92	-.70
100	.13	-.13

Leading-edge radius:1.58. Slope of radius through end of chord: 0.305.

Slotted Flap		
Station	Upper surface	Lower surface
0	-1.29	-1.29
.40	-.32	-2.05
.72	.04	-2.21
1.36	.61	-2.36
2.00	1.04	-2.41
2.64	1.40	-2.41
3.92	1.94	-
5.20	2.30	-
5.66	-	-2.16
6.48	2.53	-
7.76	2.63	-
9.03	2.58	-
10.31	2.46	-
15.66	1.68	-1.23
20.66	.92	-.70
25.66	.13	-.13

Center of leading-edge arc: 0.91 -1.29

Leading-edge radius: 0.91

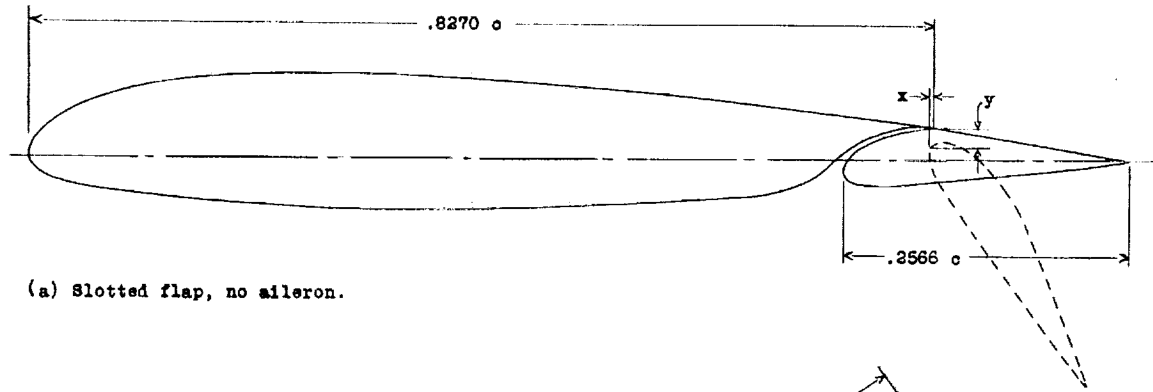
Contour of Slot	
Station	Ordinate
72.32	-1.02
74.57	.67
76.32	1.76
77.82	2.30
79.32	2.65
80.82	2.82
82.70	2.64

Radius of arc: 7.97

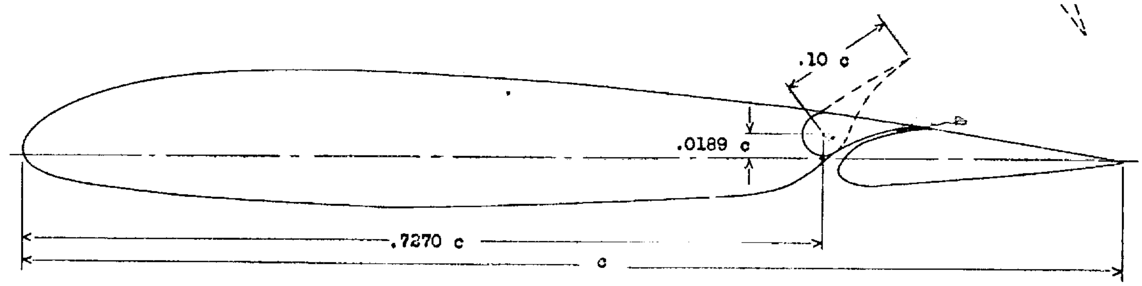
Center of arc: 66.65 4.67

(Distances measured from trailing edge of slot lip)

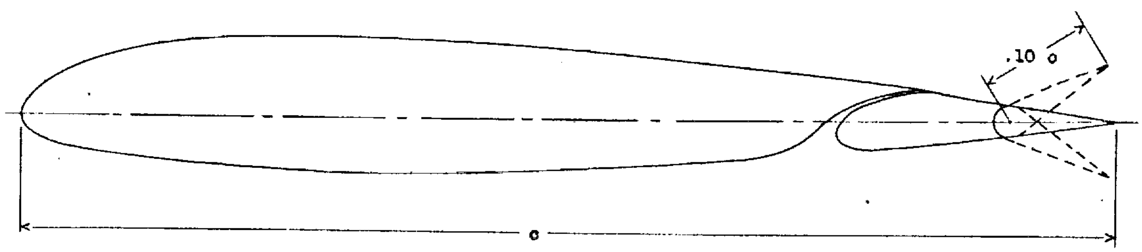
Path of Flap Nose		
δ_f (deg.)	x	y
0	8.36	3.91
10	5.41	3.63
20	3.83	3.45
30	2.63	3.37
40	1.35	2.43
50	.50	1.63
60	.12	1.48



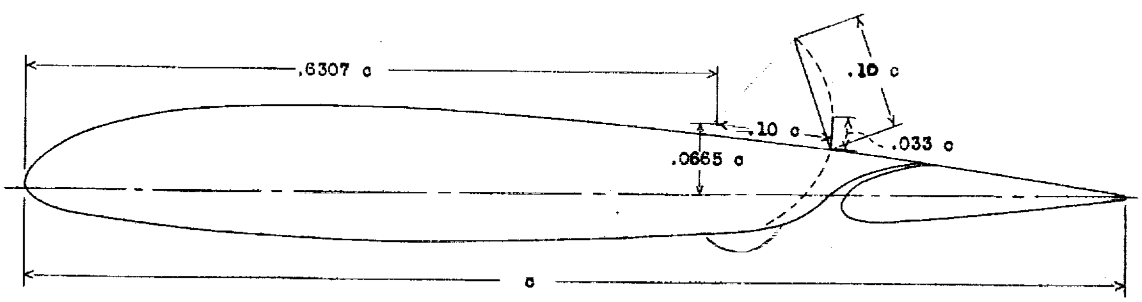
(a) Slotted flap, no aileron.



(b) Slot-lip aileron.



(c) Plain aileron.



(d) Retractable aileron.

Figure 1. - Section view of an N.A.C.A. 23012 airfoil.

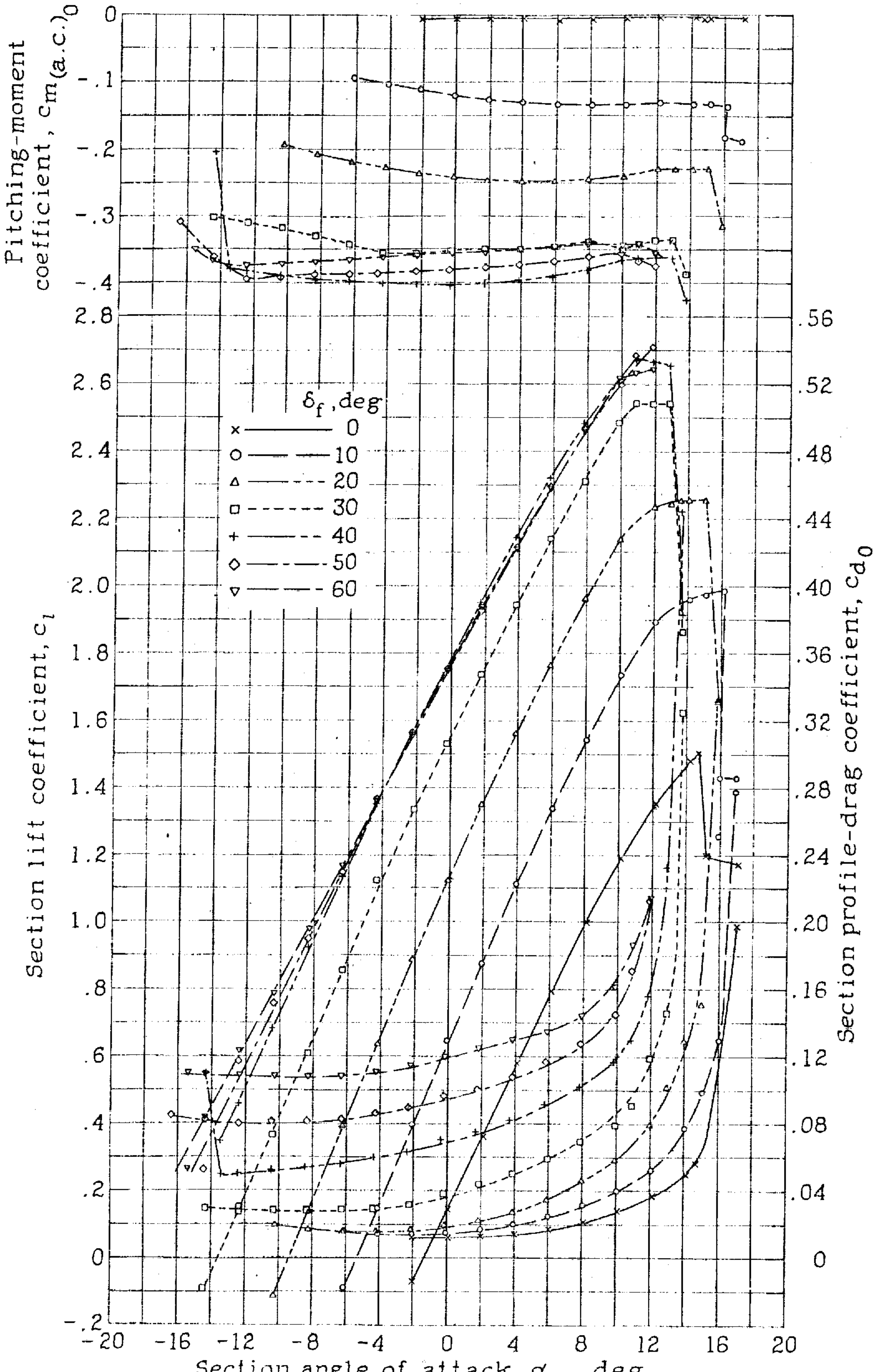


Figure 2.- Section lift, drag, and pitching-moment coefficients of N.A.C.A. 23012 airfoil with full-span slotted flap.

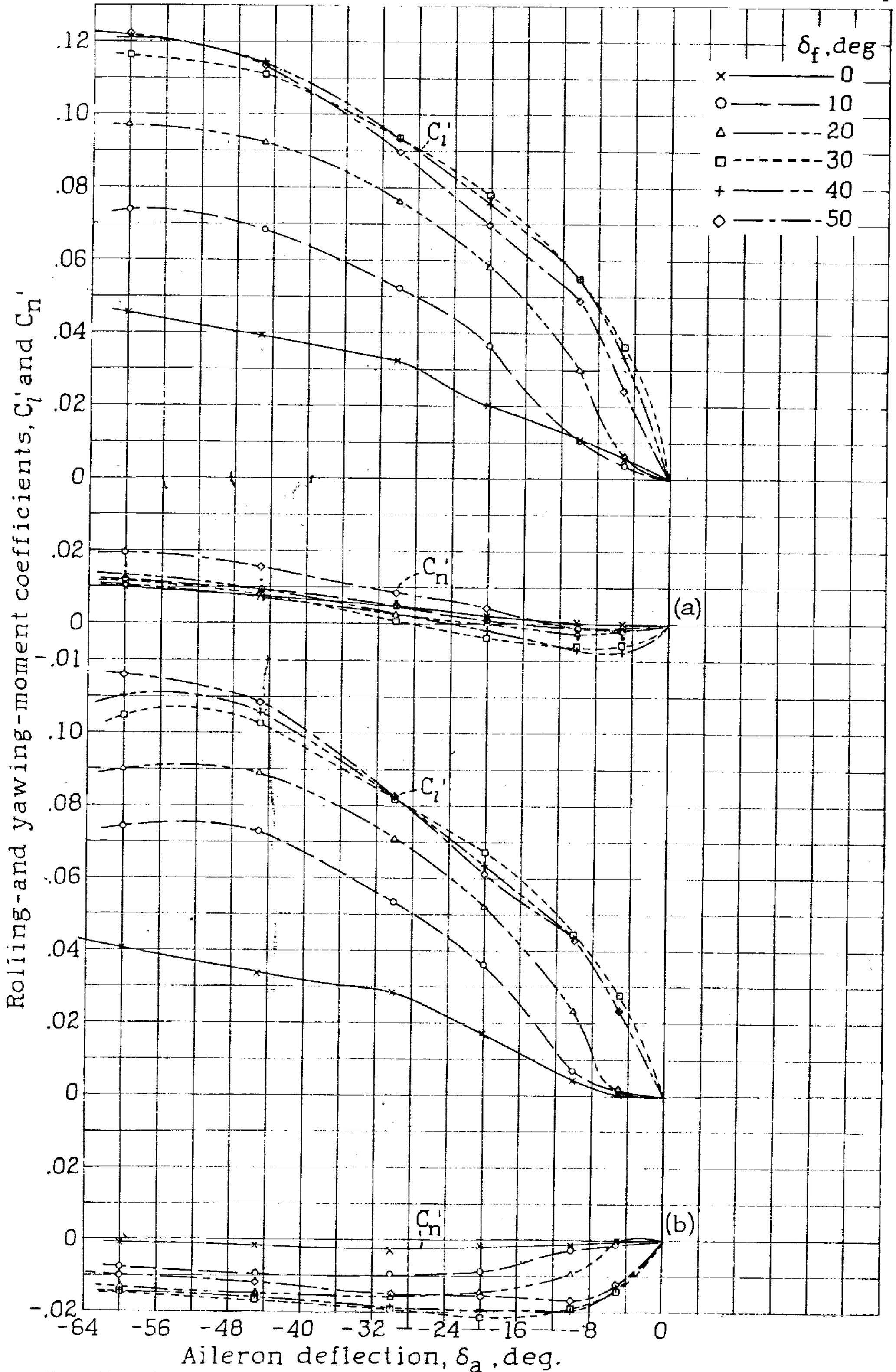


Figure 3.- Rolling-moment and yawing-moment coefficients of slot-lip ailerons on an N.A.C.A. 23012 rectangular wing of aspect ratio 6 with full-span slotted flap. (a) $\alpha = 0$, (b) $\alpha = 12°$.

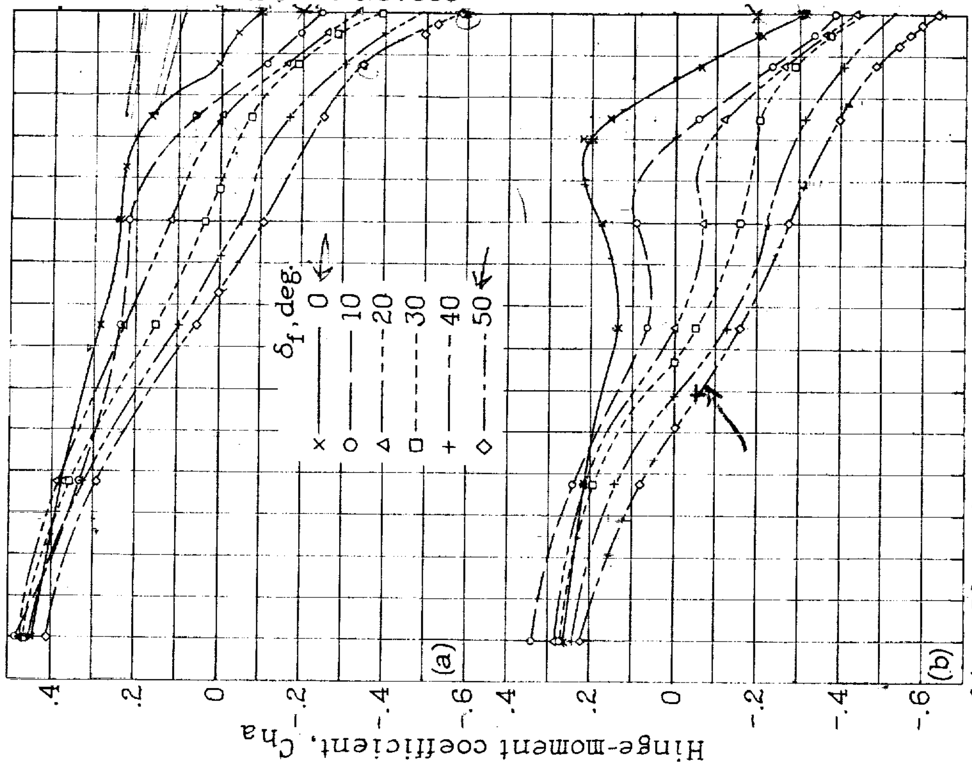


Figure 4.- Hinge-moment coefficients of slot-lip ailerons on an N.A.C.A. 23012 rectangular wing of aspect ratio 6 with full-span slotted flap. (a) $\alpha = 0°$, (b) $\alpha = 12°$

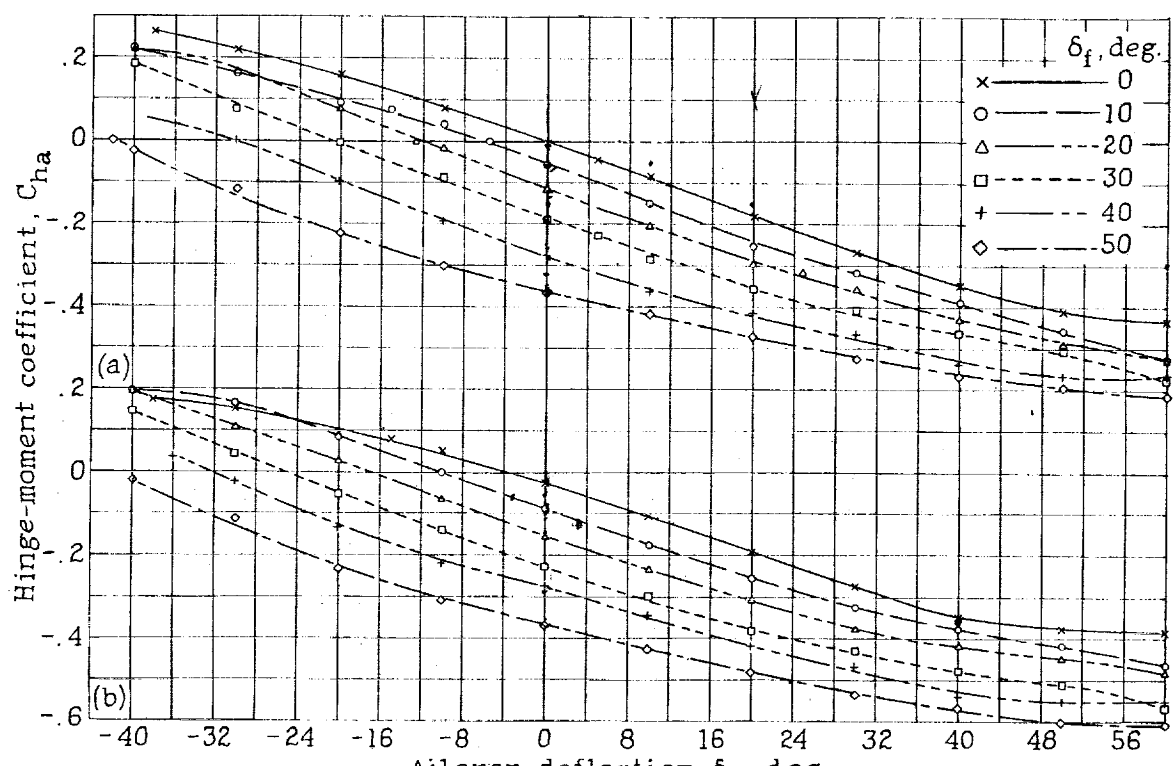


Figure 6.- Hinge-moment coefficients of plain ailerons on the full-span slotted flap of an N.A.C.A. 23012 rectangular wing of aspect ratio 6. (a) $\alpha = 0°$, (b) $\alpha = 12°$.

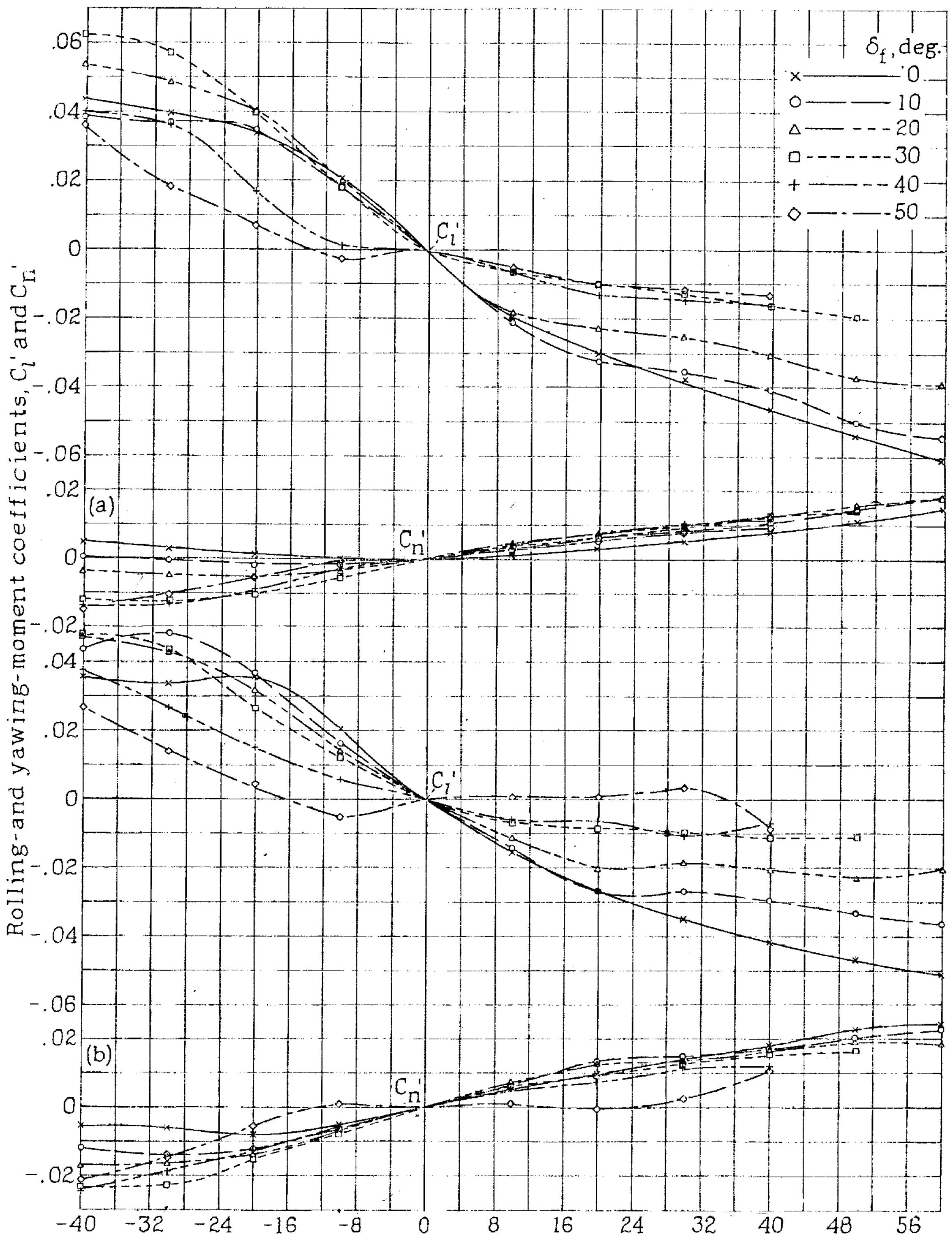


Figure 5.- Rolling-moment and yawing-moment coefficients of plain ailerons on the full-span slotted flap of an N.A.C.A. 23012 rectangular wing of aspect ratio 6. (a) $\alpha = 0°$, (b) $\alpha = 12°$

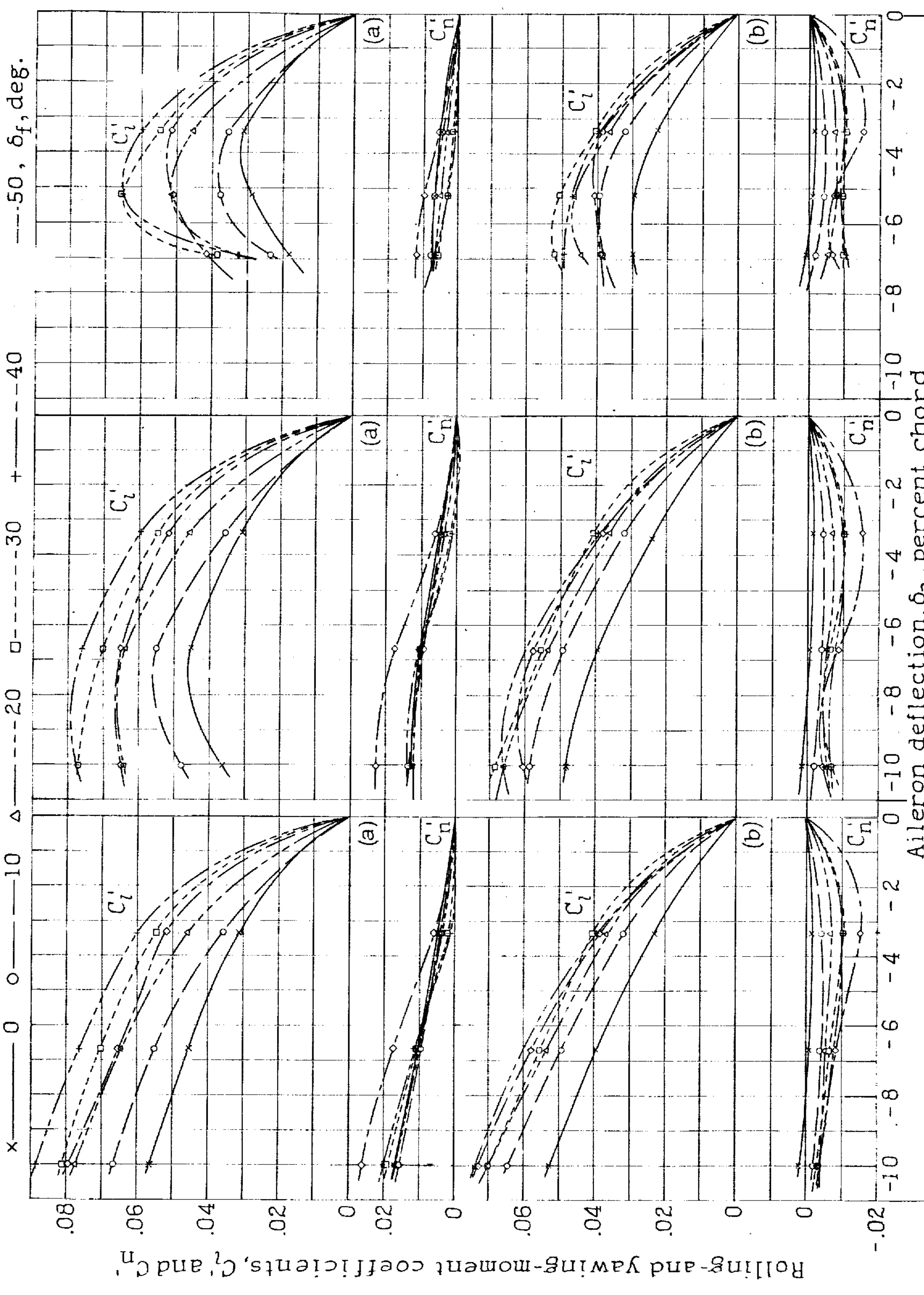


Fig. 7- Of.10c retractable ailrns. Fig.8-Of.0667c retrct.ailerons. Fig. 9-Of.0333c retrct.ailerons

Rolling-moment and yawing-moment coefficients-on an N.A.C.A.23012 rectangular wing of aspect ratio 6 with full-span slotted flap. (a) α = 0°. (b) α = 12°.